

**Using the 2S80 Series Resolver-to-Digital Converters with Synchros:
Solid-State Scott-T Circuit**

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INTRODUCTION

The 2S80, 2S81, and 2S82 are monolithic, tracking converters that are designed to interface to four-wire resolver format signals with nominal 2 V rms amplitudes. These devices can also be used with synchro format signals if an external circuit is employed which accomplishes the transformation from synchro to resolver format. Traditionally, this conversion has been accomplished with a Scott connected transformer, commonly referred to as the Scott-T transformer (Figure 1).

While a well designed Scott-T transformer makes for a very simple galvanically isolated synchro-to-resolver conversion system, the high cost and large size of transformers (particularly when operating at 60 Hz) may negate the benefits of a monolithic resolver-to-digital converter.

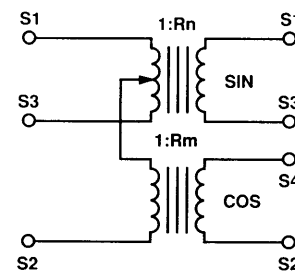


Figure 1. Synchro-to-Resolver Format Scott Connected Transformer

If the design does not require the galvanic isolation intrinsic to the Scott-T transformer, a simple solid-state circuit like that shown in Figure 2 can be used. By using precision resistors and/or trimming the circuit, performance can be achieved comparable with high quality Scott-T transformers, while realizing considerable savings in cost and size.

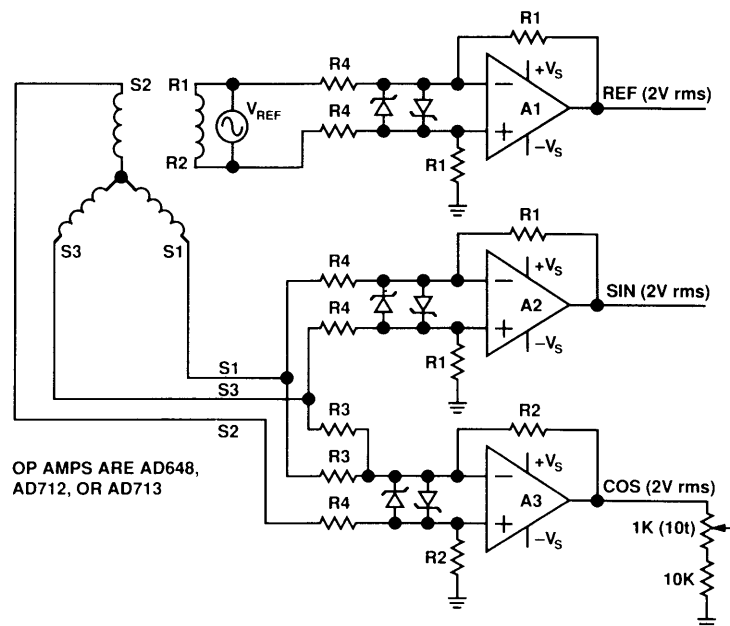


Figure 2. Solid-State Scott-T Circuit

RESOLVERS AND SYNCHROS

The resolver is an electromagnetic, rotational device that detects angular displacement. An equivalent electrical representation and diagram of typical output signal formats for a resolver are shown in Figure 3. An ac excitation signal applied to the primary (rotor) is inductively coupled to the secondary (stator). The transformation ratios are amplitude modulated by the sin and cosine of the angle of the rotor relative to the stator.

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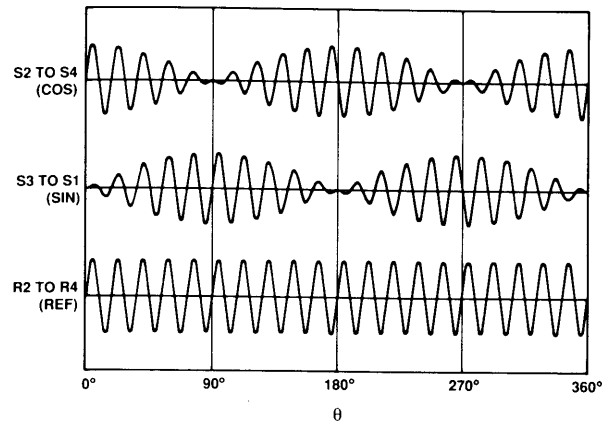
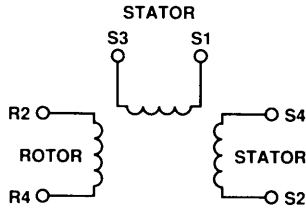


Figure 3. Electrical Representation and Typical Resolver Signals

The operation of the synchro, Figure 4, is very similar to that of the resolver. The fundamental difference is that the stator windings of the synchro are connected in a

“Y” configuration, spaced 120 degrees apart, while the resolver has two isolated windings separated by 90 degrees.

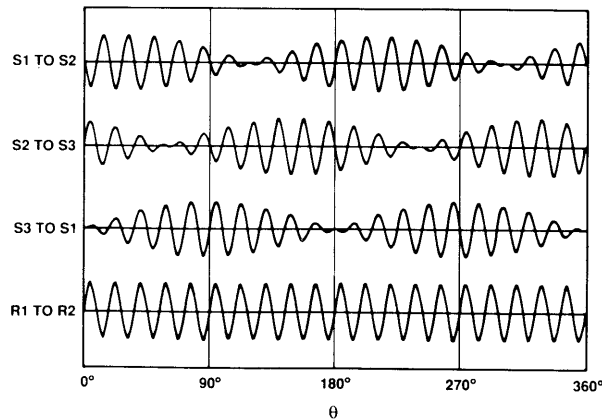
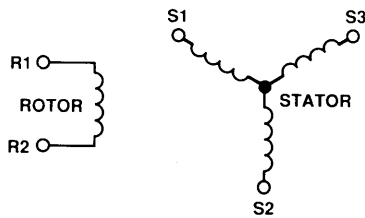


Figure 4. Electrical Representation and Typical Synchro Signals

THEORY OF OPERATION

The solid-state Scott-T circuit illustrated in Figure 2 uses two operational amplifiers to transform a synchro format signal into a resolver format. A third amplifier is used to provide a differential input for the reference signal.

The synchro format input voltages can be written in the form:

$$V_{S3-S1} = KV_{REF} \sin \theta \quad (1)$$

$$V_{S2-S3} = KV_{REF} \sin (\theta + 120^\circ) \quad (2)$$

$$V_{S1-S2} = KV_{REF} \sin (\theta + 240^\circ) \quad (3)$$

where K is the transformation ratio of the transducer and θ is the shaft angle.

In the above notation, V_{Si-Sj} refers to voltage between synchro stator terminals S_i and S_j . The order of the indices indicates the polarity/phase of the signal, e.g., V_{S3-S1} represents the voltage at S3 measured with respect to S1. The above assume that the reference voltage applied across the rotor of the synchro is of the form:

$$V_{REF} = V_{R1}-V_{R2} = V_O \sin \omega t \quad (4)$$

The normal convention is for R1 to be taken as the high potential side of the reference excitation, thus making the quantity V_{R1-R2} positive, i.e., for shaft positions between 0° and 180° , V_{S3-S1} will be in time phase with V_{R1-R2} . These conventions are consistent with those of MIL-S-20708.

The objective of the circuit is to convert synchro signals to resolver format signals of the form:

$$V_{S3-S1} = KV_{REF} \sin \theta \quad (\text{SIN}) \quad (5)$$

$$V_{S2-S4} = KV_{REF} \cos \theta \quad (\text{COS}) \quad (6)$$

where for a resolver, the reference voltage is taken as:

$$V_{REF} = V_{R2}-V_{R4} = V_O \sin \omega t \quad (7)$$

Equations 5, 6, and 7 are based on the conventions used in MIL-R-21530 for the case where the reference excitation is applied across the R2-R4 rotor winding and R2 is taken as the high potential side.

MIL-R-21530 is essentially a specification for a brush type resolver. Brushless resolvers, typically with a single rotor winding, may use a different phasing convention. If it is desired to use this solid-state Scott-T circuit to emulate a brushless resolver, the resolver manufacturer's phasing equations should be consulted for consistency with Equations 5, 6, and 7. Different phasing conventions will result in positional offsets in multiples of 90° and/or sense of rotation reversals.

The signal represented by Equation 5 is directly satisfied by one of the synchro signals, Equation 1. Operational amplifier A2, acting as a differential inverting buffer, inverts V_{S1-S3} thus producing the resolver SIN signal. The Zener diodes on the inputs simply limit the applied voltages to the amplifier to guard against component

damage. The series input resistors may be scaled to adjust the gain/attenuation of the amplifier.

The second resolver signal, Equation 6, can be shown to be a linear combination of the signals in Equations 2 and 3:

$$V_{S2-S3} - V_{S1-S2} = KV \sin \omega t (\sin [\theta + 120^\circ] - \sin [\theta + 240^\circ]) \quad (8)$$

Using the trigonometric identity:

$$\sin (A + B) = \sin A \cos B + \cos A \sin B \quad (9)$$

it is then possible to show that

$$\begin{aligned} & \sin (\theta + 120^\circ) - \sin (\theta + 240^\circ) = \\ & \sin \theta \cos (120^\circ) + \cos \theta \sin (120^\circ) \\ & - \sin \theta \cos (240^\circ) - \cos \theta \sin (240^\circ) \\ & = -\frac{1}{2} \sin \theta + \frac{\sqrt{3}}{2} \cos \theta + \frac{1}{2} \sin \theta + \frac{\sqrt{3}}{2} \cos \theta \\ & = \sqrt{3} \cos \theta \end{aligned} \quad (10)$$

Operational amplifier A3 is configured as a differential summing amplifier and accomplishes the computation function:

$$V_{S3-S2} + V_{S1-S2} = -(V_{S2-S3} - V_{S1-S2}) \alpha - \cos \theta \quad (11)$$

Since A3 also inverts the input signals, the output of A3 is thus the resolver COS signal.

The feedback resistor, R2, and series input resistors, R3, are chosen such that the gain of the amplifier is $1/\sqrt{3}$ for 2 V rms inputs and scaled proportionately for other signal levels, i.e.,

$$\frac{R2}{R3} = \frac{2}{\sqrt{3} V_{rms}} \quad (12)$$

Since it is unlikely that the exact value of this resistor ratio can be obtained, it is suggested to use a slightly higher value for R2 and trim the output to the desired level using the potentiometer as shown in Figure 2.

RESISTIVE SCALING FOR HIGH VOLTAGE SYNCHROS

Since the 2S80, 2S81, and 2S82 all require nominal 2 V rms input signal amplitudes, it may be necessary to adjust the signal levels from the synchro. This can be easily accomplished by adjusting the values of the input resistors (R3, R4) to the op amps shown in the schematic. Note that because the amplifiers may be operating at less than unity gain, internally compensated amplifiers are recommended in order to reduce the susceptibility to oscillation. The AD712 (dual), AD713 (quad), and AD648 (dual) are suggested.

In addition to galvanic isolation, transformer coupling also significantly improves the common mode rejection on the inputs to the converter. The circuit shown in Figure 2 also enhances the common mode rejection of the system by virtue of the differential amplifier configuration of the circuitry on both the reference and signal inputs. As with any differential amplifier, the common

mode rejection ratio will be enhanced with closely matched resistance on the inverting and noninverting inputs of the operational amplifier. For example 0.01% tolerance resistors will yield a typical 80 dB CMRR with a worst case of 68 dB.

The table below summarizes suggested values of the resistors in the circuit for various standard synchro voltages. The values indicated are standard values for precision (1% or better) resistors. The last entry in the table gives generalized formulae for the resistor values as a function of an arbitrary signal voltage. In addition, please note that the value of R4 may differ in the signal and reference differential amplifier circuits (e.g., an 11.8 V signal synchro is often excited at 26 V rms).

Signal Voltage (V rms)	R1	R2	R3	R4
2.0	11K	12.7K	22.6K	11.3K
11.8	11K	12.7K	133K	66.5K
26	11K	12.7K	280K	140K
90	11K	12.7K	1.18M	590K
115 (REF only)	11K	—	—	620K
V	R	1.155*R	V*R	V*R/2

CIRCUIT ACCURACY

The accuracy of the solid-state Scott-T circuit is determined primarily by the accuracy of the resistors. While absolute values are not critical, the resistors should be matched in pairs on the inputs to the operational amplifiers in order to obtain maximum accuracy. Typically, 0.1% or better tolerance values are best.

Most critical is to maintain the ratios of $R1:R2 = 1.1547$ and $R3:R4 = 2$. Note that the number of different resistor values required can be reduced if R4 is constructed by using two resistors of value R3 in parallel (alternatively, R3 can be two R4 value resistors in series). In either case, the use of resistor networks may offer significant cost and size reductions.

If 0.1% tolerance resistors are used, the angular errors introduced by the solid-state Scott-T circuit will range from 2 arc minutes (typical) to 7 arc minutes (maximum). This is additional error which must be added to the accuracy specification of the converter in a worst case analysis. Substantially better accuracy is achievable through the use of matched pairs and/or networks, as the angular errors are proportional to resistor inaccuracies.

If the necessary precision resistors can not be obtained, it is suggested that the gain of the COS circuit in Figure 2 be increased by increasing the value of R2. The output of the circuit may then be attenuated using a potentiometer so that its gain is precisely matched to that of the SIN circuit.